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MORPHOLOGIC ANALYSIS OF SEBASTIAN INLET, FLORIDA: ENHANCEMENTS TO THE TIDAL INLET RESERVOIR MODEL

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Abstract: Geomorphic analysis was conducted for Sebastian Inlet, FL to re-formulate an analytic model of shoal evolution and sediment bypassing. The Tidal Inlet Reservoir Model (Kraus 2002) was enhanced to include sediment pathways that allow seasonal reversals in littoral sand transport and episodic sand by- passing from an intra-inlet sand trap. The model was established with the aid of historical morphologic data from Sebastian Inlet, interpreted together with process data.

INTRODUCTION

Sand management at stabilized tidal inlets has often resulted in unforeseen consequences for the adjacent shoreface and beach. To quantify the inlet-beach interactions at Sebastian Inlet and develop a protocol for examining other similar inlet systems, a combination of geomorphic analysis and analytic models was applied to resolve the long-term change and sediment budget. Sebastian Inlet, located on the central East Coast of Florida (Fig. 1), is a managed system created at the local of a former natural inlet and stabilized by offset jetties. The inlet system can be considered microtidal, having an ocean tidal range of approximately 1 m, a moderate wave climate.

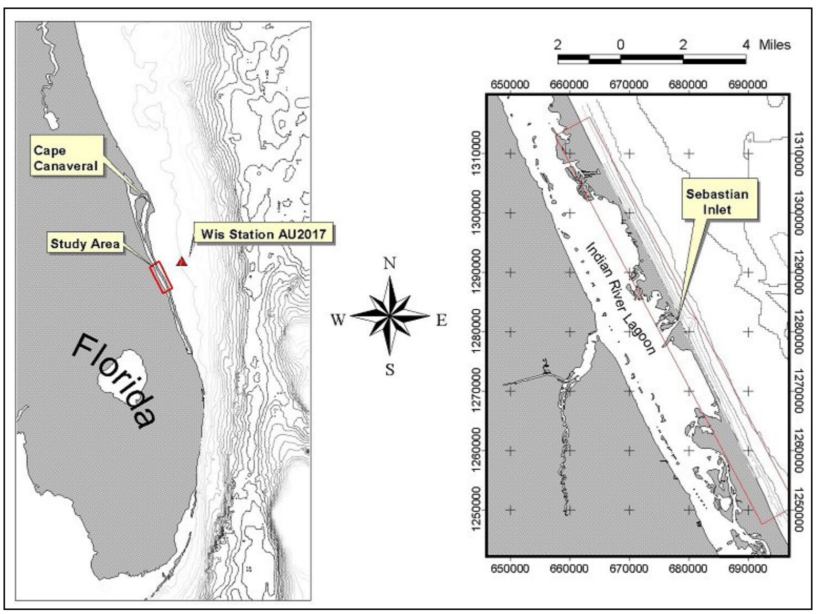

Fig. 1. Location of Sebastian Inlet on east central coast of Florida.

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In addition to these geomorphic features typical of microtidal inlets, Sebastian Inlet is also influenced by the structural control exerted by a relatively shallow, lithified carbonate platform locally identified as the Anastasia Formation. The Anastasia is composed of shell material and a small siliciclastic component deposited in a shallow marine environment in the Late Pleistocene Epoch (White 1970). The present configuration of Sebastian Inlet was artificially cut into the coquina rock of the Anastasia in 1948, and the depth of the inlet throat section is constrained by this surface. The Anastasia is veneered by adjacent beach and shoreface deposits and is frequently exposed in the surfzone and in nearshore zone on the south side of the inlet entrance (Fig. 2).

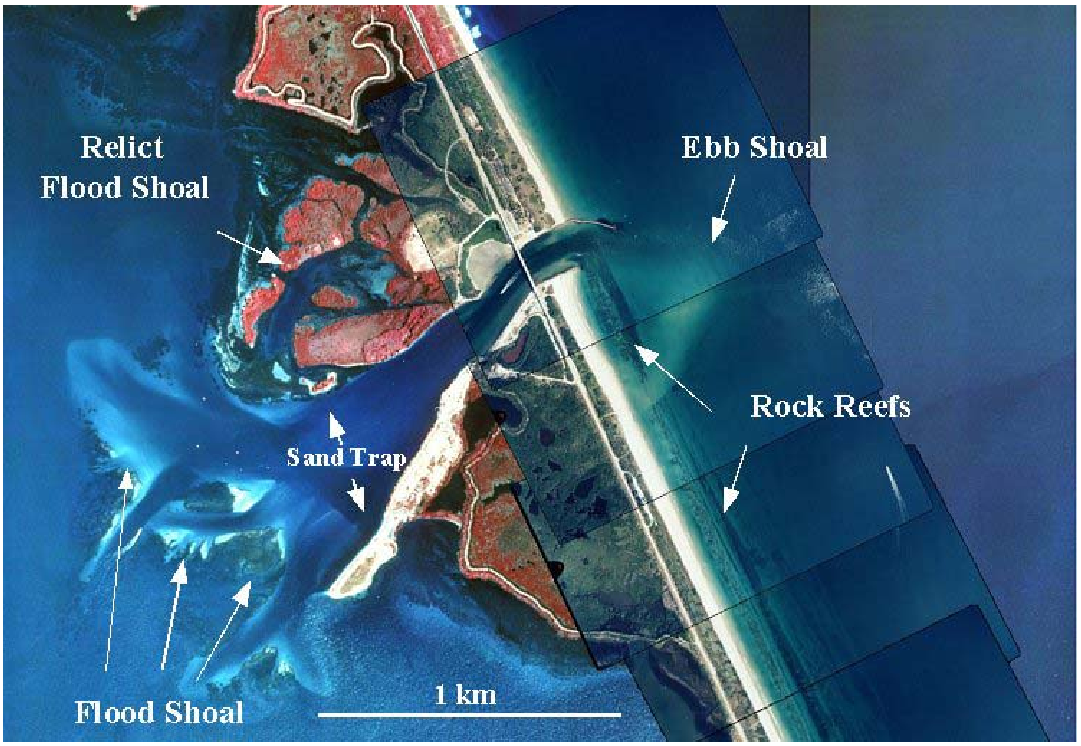

Fig. 2. Configuration of Sebastian Inlet in 2000.

The adjacent barrier island rarely exceeds 2 km in width or 10 m in elevation (Zarillo and Dolvin 1994). Visual inspection of aerial photography reveals several areas of breaching by tidal inlets and overwashing by storms. The local tidal range of approximately 1 m and a mean annual wave height of 0.6 m, indicate features of a wave-dominated coast (Hayes 1979). Major episodic wave generating events include tropical Atlantic cyclones, occurring from June to November, and temperate cyclones, or northeasters, from October to April.

The Sebastian Inlet Management Plan requires semiannual topographic surveys and annual high-resolution aerial photography to track the volume and morphology of the major geomorphic components and shoreline positions adjacent to the inlet. The sand management plans includes sand bypassing from a dredged sand trap located on the seaward side of the flood shoal and landward of the inlet throat section (Fig. 2). The repeated topographic surveys, nearly 50 years of aerial photography, and frequent collection of process data provide an unusually good database for understanding and managing sand resources at an inlet.

WAVE CLIMATE

An understanding of the local wave climate was developed from long-term wave hind casts and with measurements from a directional wave located near Sebastian Inlet during the 1994-95 period. Wave Information System (WIS) hind cast data are available from the U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory. These were generated by basin-scale modeling of water wave heights from historical wind fields, providing the results at a number of coastal stations, roughly following the 25-m contour (Hubertz, et. al. 1996). Significant wave height, dominant period, and dominant direction were extracted from the Level 2 station nearest to Sebastian Inlet, A20017 (located approximately 20 km offshore, Fig. 1).

Wave power and direction for 22 years of WIS data (1976-1998) were divided into two groups in a joint probability analysis for Spring/Summer, between April and September, and for Fall/Winter, between October and March. Figure 3 displays the joint probability distributions for both Spring/Summer and Winter/Fall. The Spring/Summer season is dominated by low energy (power) events arriving from an azimuth of 85 to 100 deg. The Fall/Winter probabilities do not present such a coherent picture. There is a small predominance of low energy directed straight onshore, from 50 to 70 deg and a secondary peak in the same range as the predominant Spring/Summer peak. The much lower probabilities of the low power Fall/Winter events indicate a much higher occurrence of higher power events relative to the Spring/Summer.

If events are considered having wave power greater than 2.5x104 W/m corresponding to wave heights greater than 1.5-2 m and periods of 5-8 sec, peak frequencies occur in a directional bin centered around 62 deg, which is nearly shore perpendicular. If all events during the Fall/Winter above 2.5x104 W/m are integrated with respect to power, there is nearly the same total probability of power arriving from southerly directions as from more northerly directions. When only extreme events are considered having wave powers greater that 8x105 W/m (corresponding to 3-m, 9-sec waves), the peak frequency of occurrence in the Fall/Winter is from the approximately 55 deg, an oblique angle north of the shore normal direction. After these probabilities are integrated with respect to power, the frequency of events generating waves from north of the shore normal direction is about 2.5 times greater compared with similar events from the south. Figure 4 presents the joint probability of events having a power of greater than 8x105 W/m. Such extreme events from northerly directions are mainly due to powerful temperate cyclones, or northeasters, that sometimes spin off of the U.S. East Coast in the fall, winter, and occasionally during the early spring. The Spring/Summer probabilities are much lower and much more scattered with respect to direction, mainly due to tropical cyclones, which generally follow much more diverse paths compared to extratropical storms.

The joint probability analysis of wave power versus direction reveals that modal conditions are generally low energy waves approaching the shoreline from a quadrant that actually provides a weak south to north longshore forcing, which is opposite that indicated by the local inlet morphology, especially in the spring and summer months. Thus, it is the relatively infrequent powerful events, occurring primarily between the months of October and March and arriving from the northeast that provide the necessary longshore forcing for the net north to south transport that is apparent in this region of central Florida (Coastal Technology Corp. 1989; Hoeke 2001).

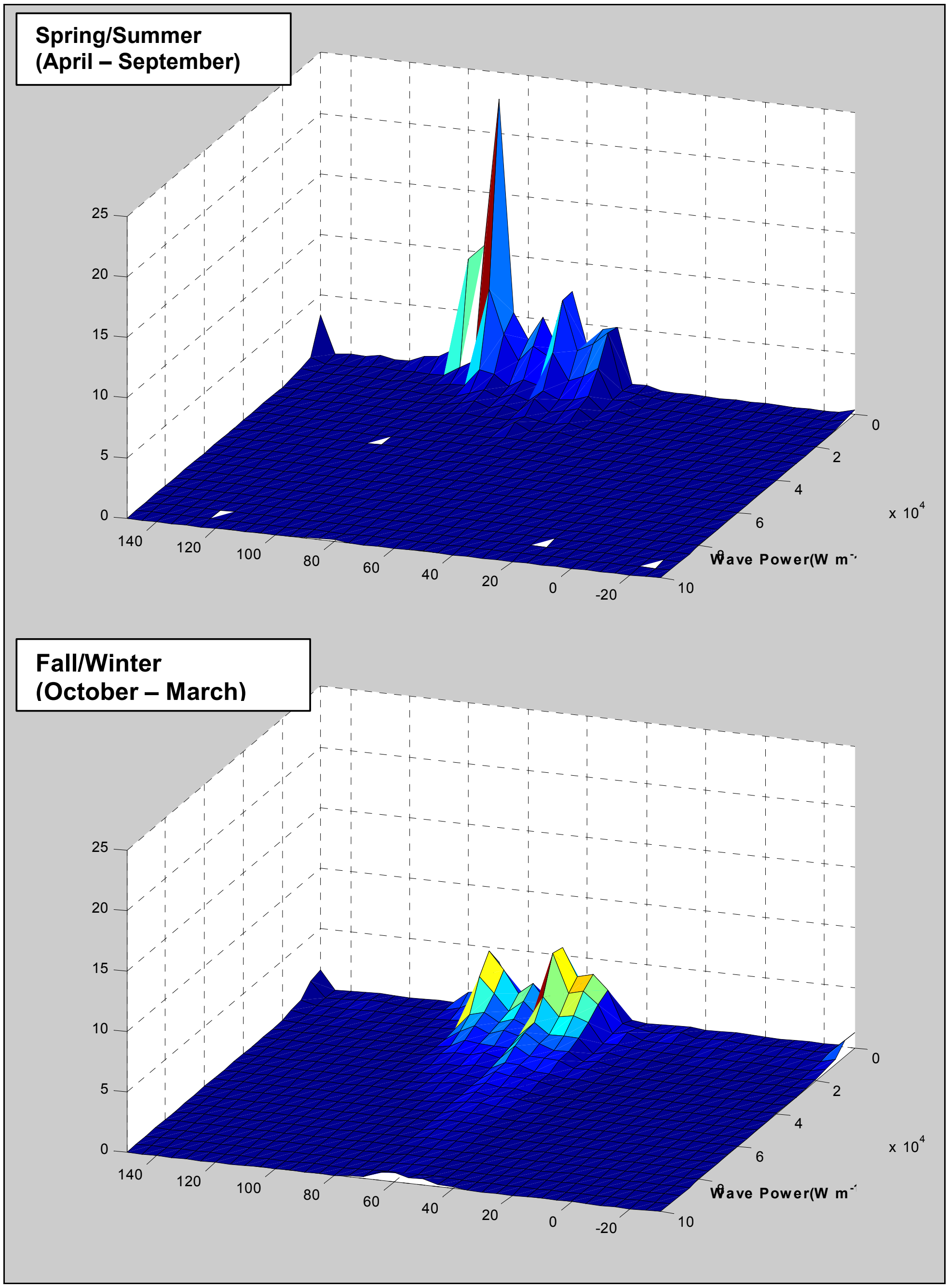

Fig. 3. Seasonal joint probability distributions of wave power vs. direction.

Shorter-term measurements of wave data in the vicinity of Sebastian Inlet are consistent with the interpretation of the WIS data (Fig. 5). The winter months are characterized by episodes of high longshore energy flux, whereas during the summer months, higher energy events are rare, and longshore sand transport is likely to be small. Based on analysis of wave power from the nearshore Sebastian Inlet wave gauge, net sand transport should be to the south in the winter and largely driven by storms. Transport in the summer months is weaker and more balanced between north and south-directed components.

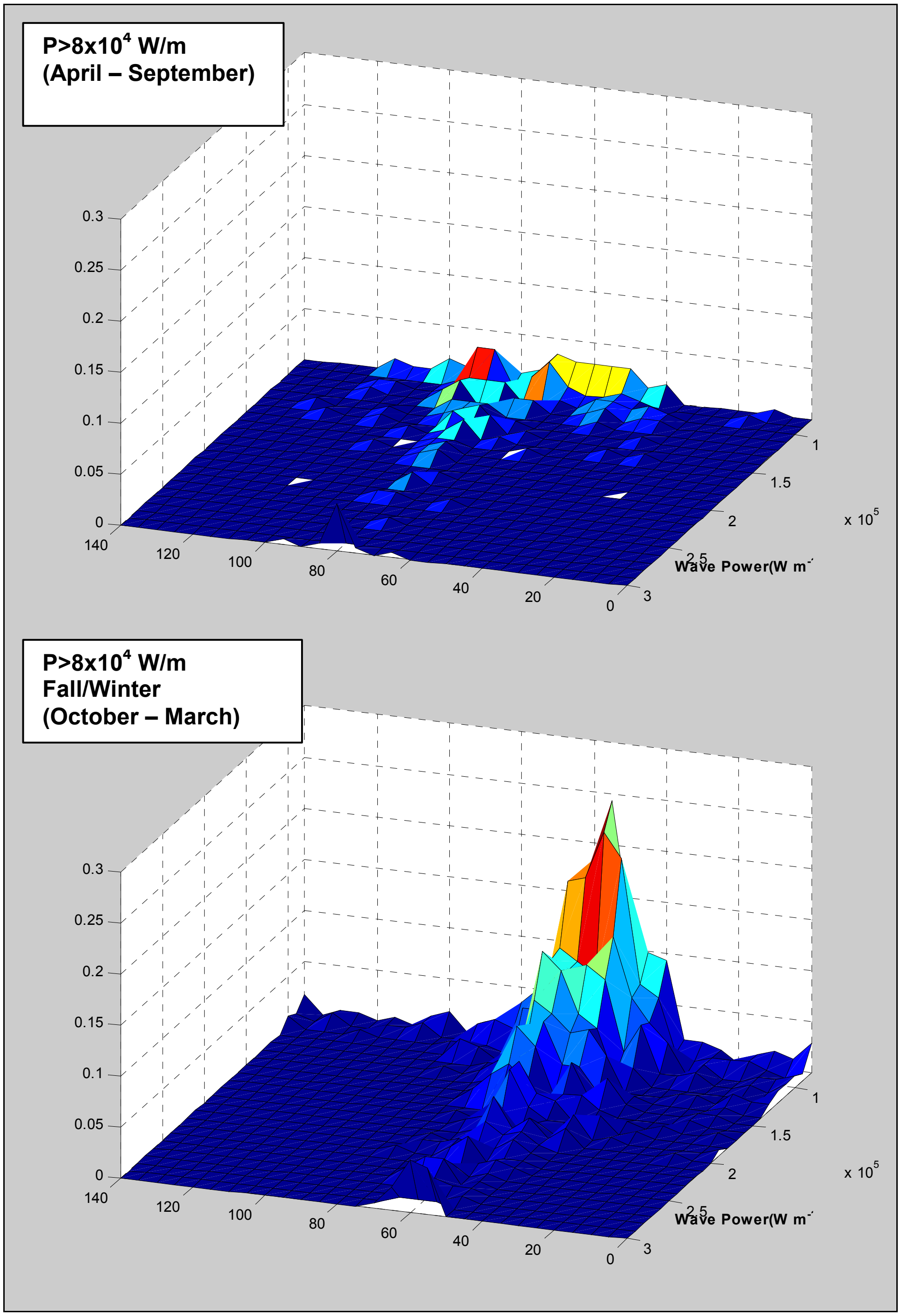

Fig. 4. Seasonal joint probability distributions of wave power vs. direction for wave power greater than $8x10^5$ W/m.

MORPHOLOGIC CHANGES OVER THE PAST 50 YEARS

Analysis of geomorphic change and of shoreline adjustments over the past 50 years indicates that Sebastian Inlet has responded to both natural factors and engineering activities (Fig. 6). To quantify the inlet changes in the long-term data were documented through historical aerial surveys and shorter-term field surveys of inlet morphology. Annual to semi-annual beach profiles and topographic surveys of the study area were collected from the summer of 1989 to the summer of 2000. These consisted of high-resolution topographic surveys of the ebb shoal, flood shoal, sand trap, and beach profiles tied in with submerged survey transects every kilometer along the shoreface.

Shoreline change

An extensive search for historical aerial photography was performed for the study area, returning 36 aerial surveys between February 1943 and July 2000. These photosets are variable with respect to spatial resolution, study area coverage, size, and quality. In general, only photographs having a spatial resolution of 1.5 m or better were retained for the study. The 23 dates selected for analysis had a minimum approximate scale of 1:25000 and covered at least one-third of the study area. Each photo was exported to a Tagged Image Format (TIF) and rectified to a Florida State Plane, East Zone projection with an NAD 1927 Datum. This projection was selected primarily because it is compatible with most historic survey data, a well-developed flood shoal that is inter-tidal, and a prominent submerged ebb shoal.

Two sources of ground control points (GCP's) served as projection references to rectify imagery, including 24 sets of DGP coordinates collected at visible landmarks and U.S. Geologic Survey Digital Ortho-Quarter-Quads (DOQQs). The USGS DOQQs were obtained in a UTM Zone 17 projection and re-projected to the study coordinate system. An image-to-image rectification process was used to collect reference points for the unrectified imagery from the DOQQs. A minimum of seven combined control points was used for each image, and these points were adjusted until the RMS error of point scatter was less than 3 m. GIS software ArcView 3.2© ImageAnalyst© was operated for the rectification process.

The beach areas of the geo-referenced images, from the wet/dry line to the vegetation line, were identified by means of supervised classification/isodata clustering. This results in the generation of a detailed polygon that is an estimation of the beach between the low-tide terrace (the wet/dry line) and the toe of the dune or the vegetation line. The photo polygons and the corresponding fly date were then merged, resulting in a continuous (except where intersected by the inlet) polygon representing the entire backshore on a given date. A baseline running the length of the study area and roughly parallel to State Road A1A, the main highway on the barrier island, was then used as a common reference for transects spaced at 7.6-m (25 ft) intervals. This customized method of determining shoreline positions using an ArcView © extension termed BEACHTOOLS is described by Hoeke and Zarillo (2001). Transects serve to determine the positions of the vegetation line and the wet/dry line and continue the same shore-parallel position throughout the time series. This procedure is applicable to a number of analyses, including changes in beach widths, quantitative erosion accretion studies, and spectral analysis for rhythmic topographies, etc. (Hoeke and Zarillo 2001).

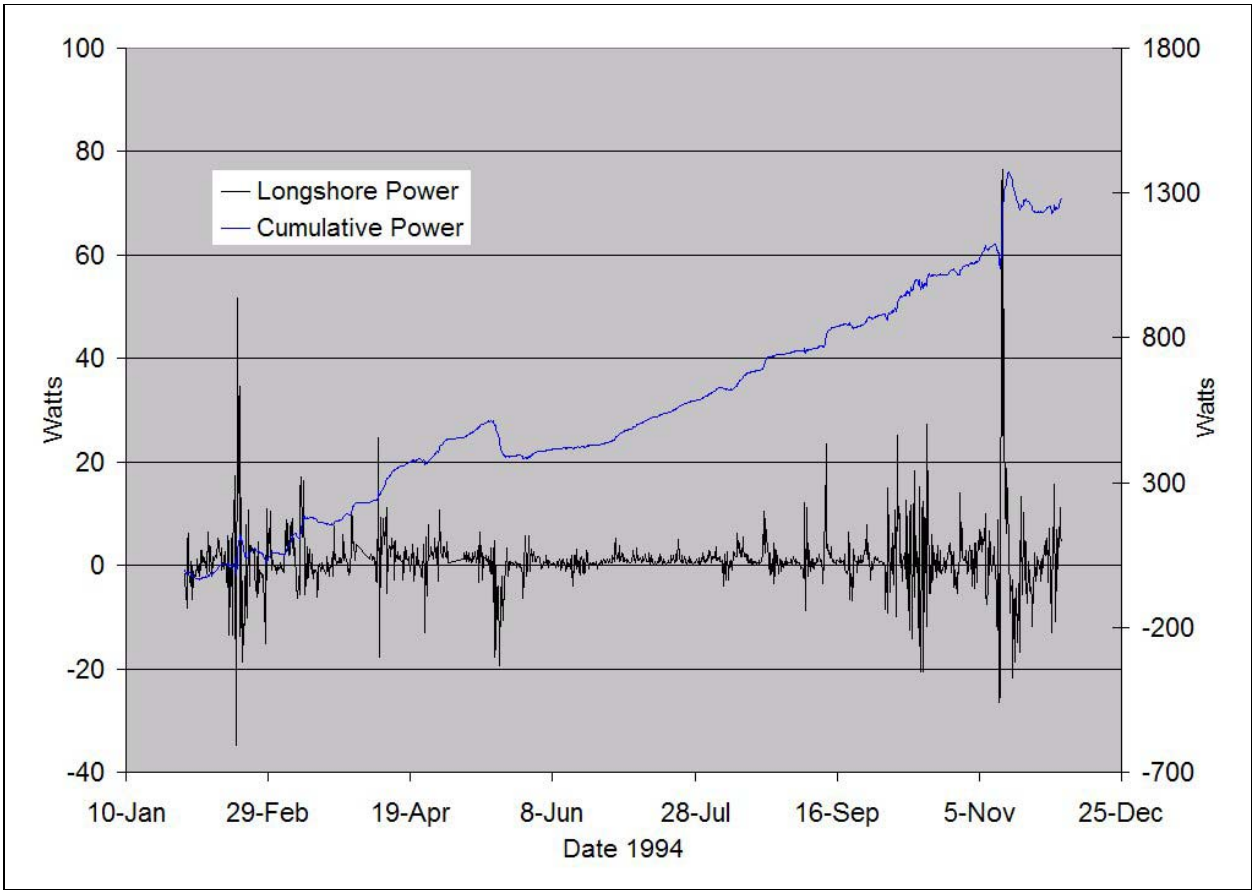

Fig. 5. Calculated longshore component of wave power (linear wave theory) from directional wave data collected in 8-m depth approximately 2 km north of Sebastian Inlet in 1994.

Figure 6 is a summary of shoreline changes in the vicinity of Sebastian Inlet from 1943 to 2000 as derived from aerial photography analysis. The sequence begins in 1943 when the inlet was temporarily closed. After being opened in 1948 the sequence of evolving shoreline position can be followed from 1958 through 1999 showing the typical build out of the north or updrift shore and retreat of the shoreline on the south or downdrift side

Shoal evolution

Topographic data were analyzed calculate volumes of various morphological features of the inlet area and design the application of the Tidal Inlet Reservoir Model (Kraus 2000). The major morphologic components analyzed for volume and included in the Reservoir Model are shown in Figure 7. The surfaces for each survey date and region were calculated by creating a triangulated irregular network (TIN), interpolating a grid from the TIN using nearest neighbor interpolation, low-pass filtering the grid, and re-triangulating the grid, creating a final, regularized TIN. Volumes for each inlet morphologic feature and the survey date were then calculated by determining the volume between a horizontal datum and the surface.

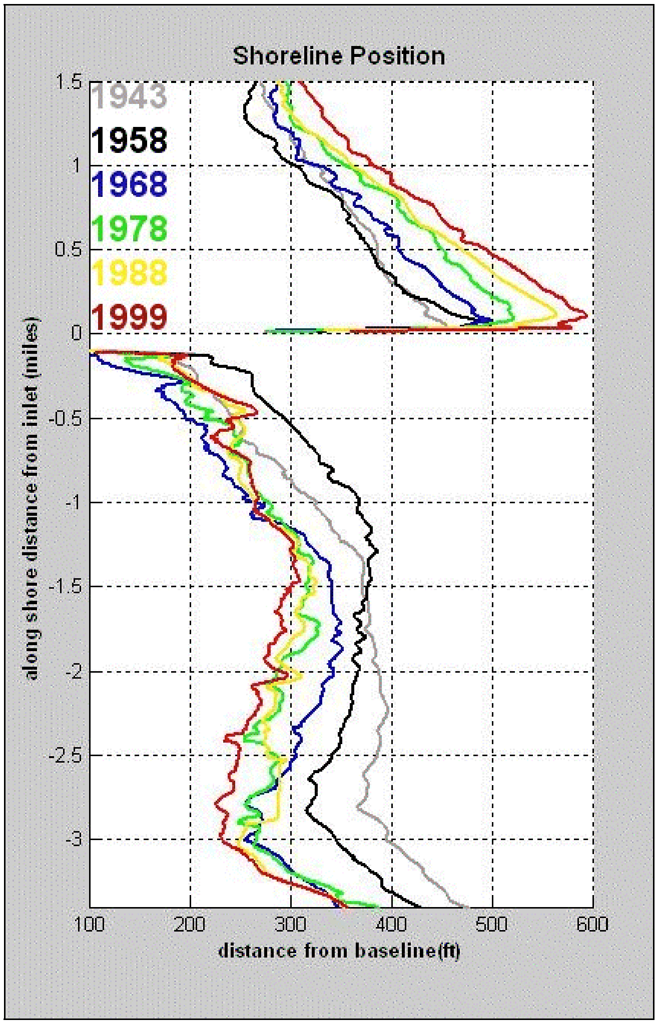

Fig. 6. Comparison of shorelines mapped from aerial photography between 1943 and 1999.

Table 1 lists the calculated volumes for the various inlet shoal systems between 1989 and 2000. Volumes for the flood shoal in 1958 and 1984 are also presented. Volumes were estimated based on the areas of the shoal determined from aerial photographs and the assumption that the shoal has an average thickness of 1.3 m, the average thickness determined from more recent topographic data.

ENHANCEMENTS TO THE TIDAL INLET RESERVOIR MODEL

Analysis of topographic and photographic data between 1989 and 2000 indicate that Sebastian Inlet may still be approaching geomorphic equilibrium with respect to the volume of both the ebb shoal and flood shoal. However, continued adjustments to the updrift and downdrift beach shown by shoreline analysis indicates that the inlet shoals are still trapping sand from the littoral supply and that some continued growth of the shoals can be expected. This provides the basis to examine the longer-term dynamics of Sebastian Inlet with the Tidal Inlet Reservoir Model (Kraus 2000). In addition, the Sebastian Inlet data set can be used to calibrate and verify the model. Model derivation and assumptions are given in Kraus (2000, 2002).

In summary, the Reservoir Model is based on the conservation of sand volume, identification of sediment pathways, and the existence of an equilibrium volume of morphologic features of the tidal inlet system. The ebb-shoal complex is defined as consisting of the ebb shoal proper, one or two ebb-shoal bypassing bars (depending on the balance between left- and right-directed longshore transport), and one or two attachment bars. These features at Sebastian Inlet are shown in Fig.7. The model distinguishes between the ebb shoal proper, typically located in the confine of the ebb-tidal jet, and the ebb-shoal bypassing bar that grows toward shore from the ebb shoal by the transport of sediment alongshore by wave action.

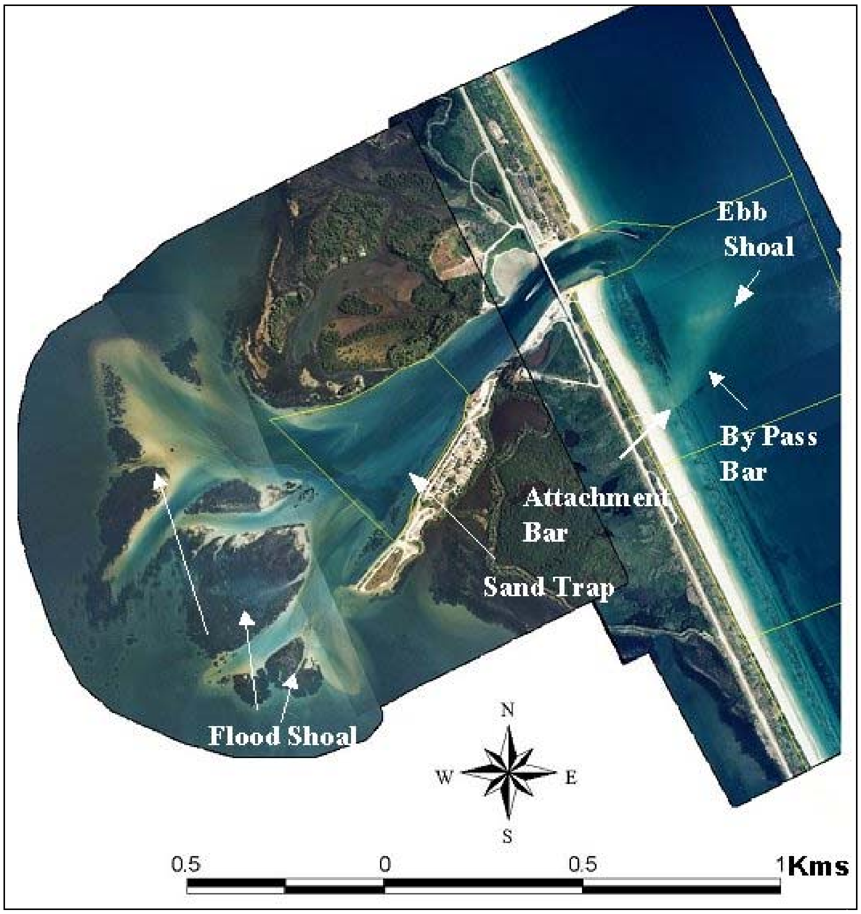

Fig. 7. Major components of Sebastian Inlet morphology and associated shoal systems included in the Reservoir Model.

The Reservoir Model represents volumes of morphologic bodies at an inlet as beakers of maximum volume identified as the equilibrium volume of the feature, to be provided from observation or prediction. Sediment transport paths are represented by rates and paths connecting the leaking beakers (Fig. 8) according to conceptualization of the acting processes. A closure relation of the model is that the output rate of material from a morphologic feature (ebb shoal, flood shoal, etc.) equals the product of the volume remaining and the rate of volume input. Equations of the Reservoir Model and a discussion of coupling coefficients that define pathways and the rates of exchange among inlet features can be found in Kraus (2002) and Militello and Kraus (2001).

Table 1 Sebastian ebb and flood shoal volumes in cubic meters

Date	Ebb Shoal	Flood Shoal
6/30/58		6.86E+05
6/30/84		1.01E+06
9/15/89	1.72E+06	1.64E+06
9/15/90	1.63E+06	1.57E+06
3/15/91	1.66E+06	1.56E+06
9/15/91	1.65E+06	1.55E+06
3/15/92	1.66E+06	1.59E+06
9/15/92	1.64E+06	1.57E+06
3/15/93	1.64E+06	1.59E+06
9/15/93	1.68E+06	1.59E+06
3/15/94	1.67E+06	1.63E+06
9/15/94	1.65E+06	1.55E+06
3/15/95	1.64E+06	1.60E+06
9/15/95	1.62E+06	1.51E+06
3/15/96	1.64E+06	1.57E+06
9/15/96	1.61E+06	1.58E+06
3/15/97	1.60E+06	1.57E+06
9/15/97	1.57E+06	1.59E+06
3/15/98	1.60E+06	
9/15/98	1.62E+06	1.61E+06
3/15/99	1.60E+06	
9/15/99	1.67E+06	1.52E+06
3/15/00	1.60E+06	

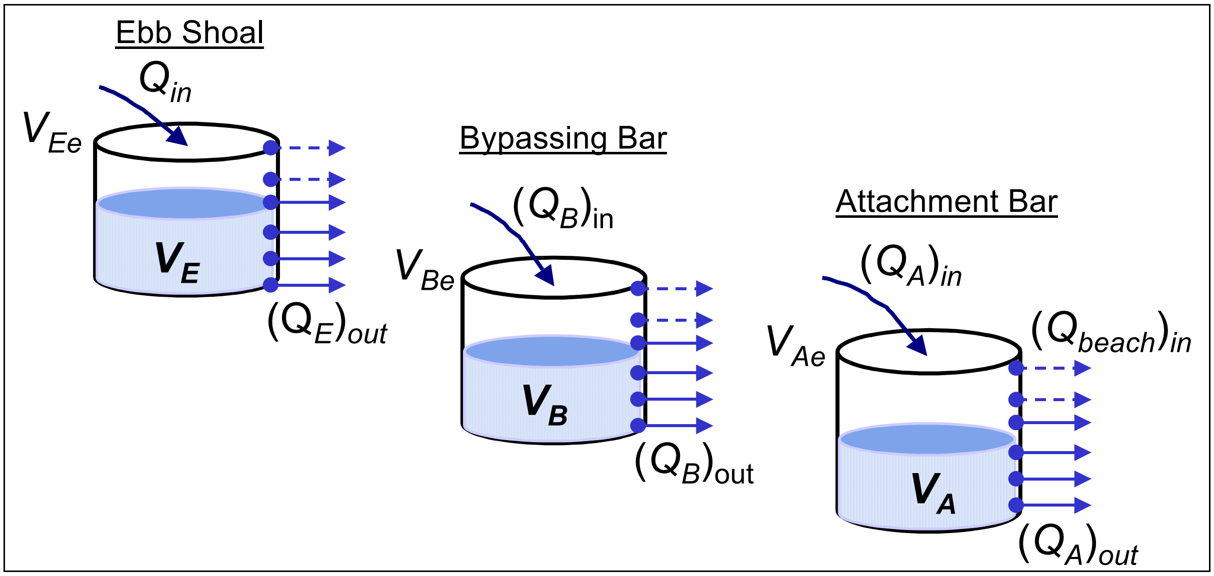

Fig. 8. Conceptual diagram for the Reservoir Model (from Kraus 2002).

Analysis of morphologic change and wave climate at Sebastian Inlet indicated the need to enhance the Reservoir Model to accommodate more complex sediment pathways. The seasonally variable wave climate and topographic configuration of the ebb shoal at Sebastian Inlet require an application of the model that includes sediment movement across the outer inlet in both north and south direction, as well as the ability to carefully partition sediment transport through the inlet conveyance channel. Furthermore, the model must be able to handle episodic removal of material from the sand trap.

Figure 9 schematically shows the various transport paths included in the enhanced Reservoir Model. Principal refinements in the Reservoir Model established for the Sebastian Inlet case were (1) the capability to "back pass" sediment to the updrift side of the inlet based on seasonal or episodic reversals in wave direction, (2) different sediment pathways according to direction of longshore transport, and (3) representation of dredging of material from the deposition basin and the channel. The deposition basin or sand trap between the flood shoal and main inlet channel was added to the list of inlet features, and the material dredged according to records was removed in the model. Model terms were also added to represent the nature of the back bay system to be a large sink for sand, and to define the rate of sediment loss to the distal reaches of the flood shoal system.

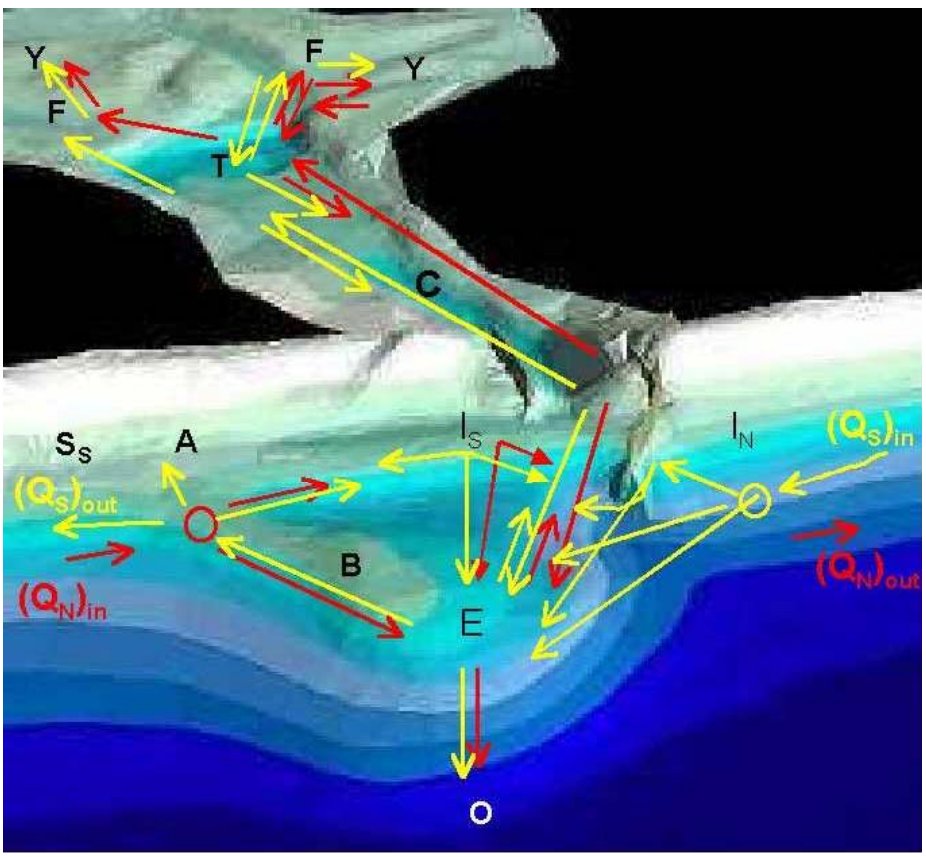

Fig. 9. Sediment pathways described in the Reservoir Model superimposed on Sebastian Inlet morphologic components (E=ebb shoal, B-bypass bar, A=attachment bar, C=channel, T=sand trap, F=flood shoal, Ss=south fillet, In= north fillet.

MODELED EVOLUTION OF SEBASTIAN INLET 1950 – 2050.

Under the assumption that the ebb and flood shoal systems of Sebastian Inlet are still evolving, but that they may be approaching an equilibrium volume, the Reservoir Model was run to simulated inlet evolution between 1950 and 2050 (Fig. 10). Based on model calibration it was assumed that the equilibrium volume of the ebb shoal is 3 m^3 million and that of the flood shoal is 4.5 million m^3. The pathways distributing sediment volume around the inlet are as defined in Figure 9. Volume loss to the offshore (O in Fig. 9) was considered minimal, and the coupling coefficient defining sediment exchange from the inlet channel (C in Fig. 8) was set to simulate flood-dominate transport of sand in accordance with the calculated inlet hydraulics (Zarillo and Surak 1995).

The gross annual longshore drift of sand in the vicinity of Sebastian Inlet was estimated at approximately 175,000 m^3 (Coastal Technology Corp. 1989). Partitioning of gross longshore drift was from the analysis of longshore wave power using the nearshore directional wave measurements (Fig. 5). Accordingly the annual drift directed to the south is estimated at approximately 125,000 m^3, whereas the annual drift to the north was estimated at 50,000 m^3. These values yield a net annual drift to the south of 75,000 m^3. Figure 10 shows the results of the model simulation and compares measured and estimated shoal volumes with predicted volumes for 1958, 1984, 1989 and 1999.

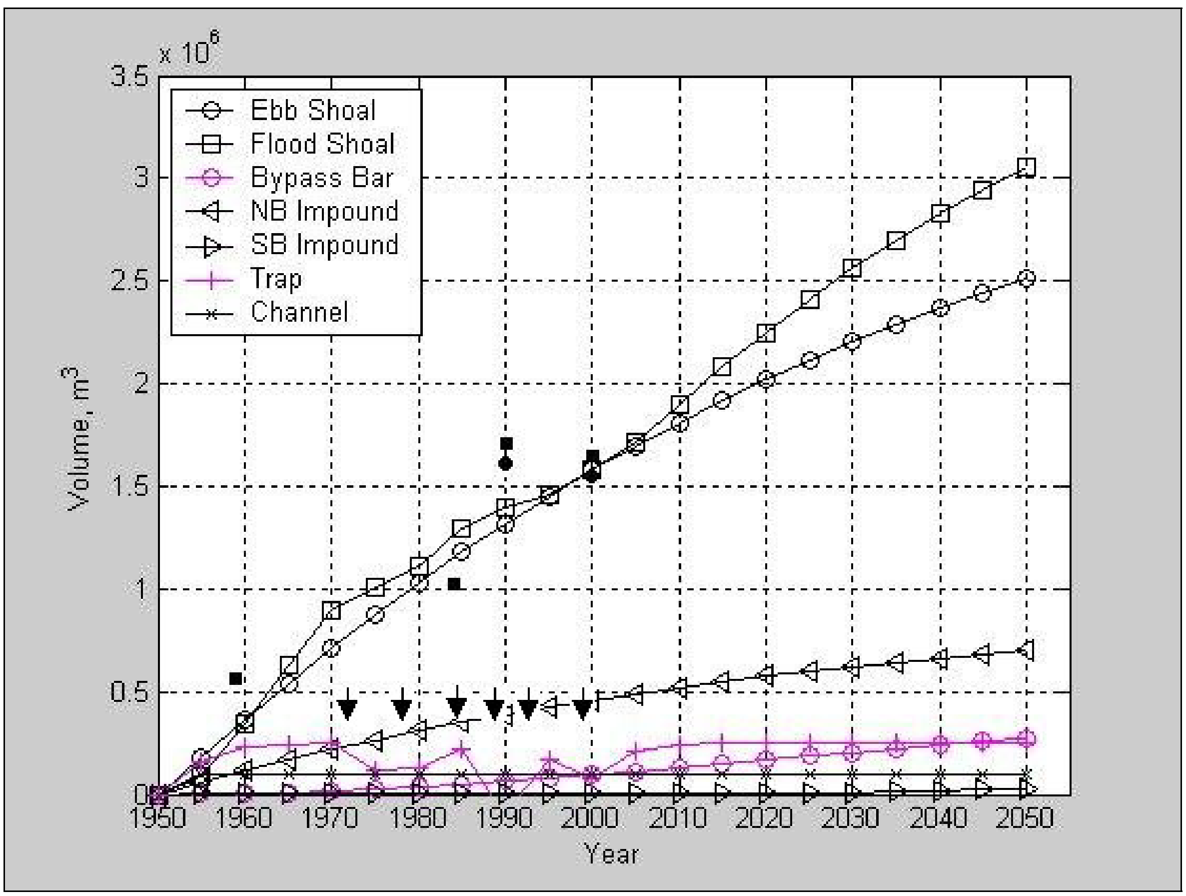

Fig. 10. Reservoir Model simulation of sediment volumes at Sebastian Inlet, 1950 to 2050. Solid symbols indicate shoal volumes estimated from topographic data and analysis of aerial images. Solid arrows indicate sand bypass events.

The Reservoir Model simulations shown in Figure 10 give a reasonable match between measured and predicted flood and ebb shoal volumes between 1950 and 2000. The model as calibrated for this study agrees closely with the most recent measurements of flood and ebb shoal volumes at Sebastian Inlet, but under predicts volumes determined for the late 1980's (Fig. 10) However, the calculations and measurements are in agreement for the past decade with respect to the overall impact of sand bypassing. Topographic data indicate a slight decrease in ebb and flood shoal volumes since 1989 (Table 1), whereas the model indicates a decrease in the rate of flood shoal growth. The model simulation shown in Figure 10 includes sediment volume removed from the sand trap during the model run to simulate sand-bypassing projects conducted between 1972 and 1999. Figure 11 illustrates shoal evolution without the prescribed of sand bypassing from the Sebastian Inlet sand trap. In this case, the volume of the flood shoal sharply increases, reflecting both the additional sand volume in the system. This result is expected under the assumption of flood-dominant sand transport with the main inlet channel (pathway C in Fig. 8) of the Reservoir Model as applied to Sebastian Inlet.

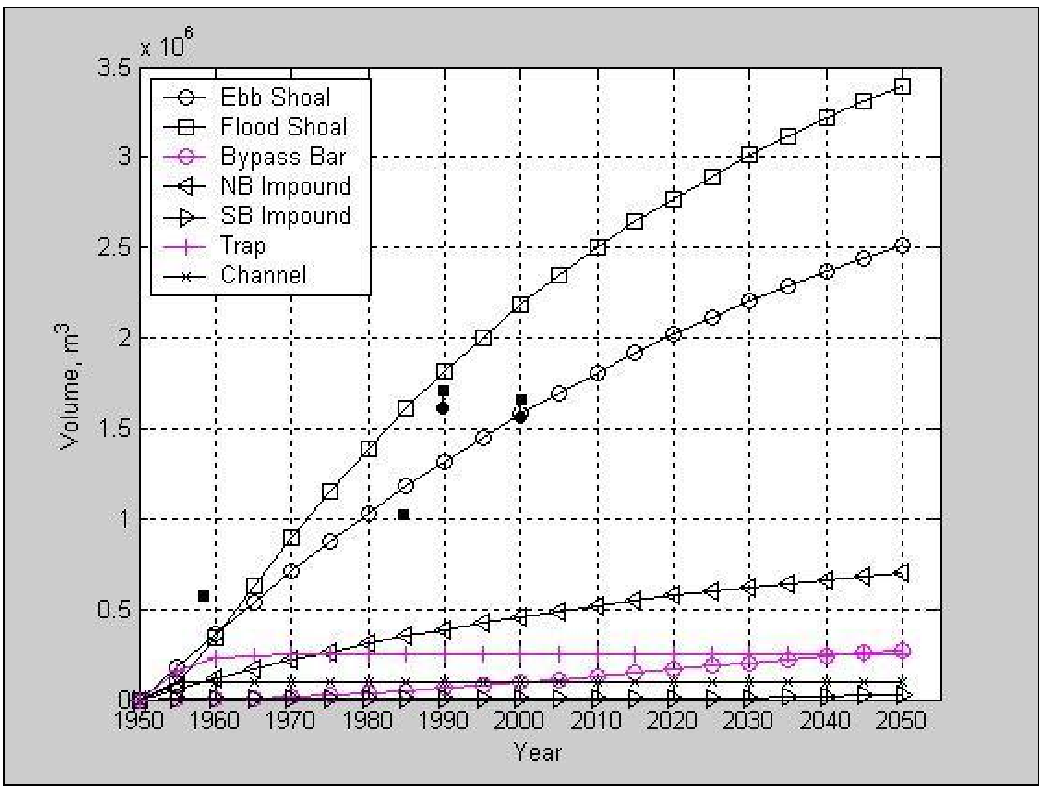

Fig. 11. Reservoir Model results without bypassing from Sebastian Inlet sand trap.

CONCLUSIONS

The Tidal Inlet Reservoir Model has been adapted to a realistic situation with a more complex system of sediment transport paths than in previous applications (Kraus 2000; Militello and Kraus 2001). In particular, seasonal and episodic reversals in longshore drift can be simulated together with bypassing of prescribed sand volumes. The model is applicable to investigation and verification of beach and inlet morphology responses to sand management plans. The model can also serve as a predictive tool to provide insight concerning possible consequences of removing sand

from each of the “reservoirs” or inlet morphologic features for bypassing and beach nourishment. In the case of Sebastian Inlet, model simulations indicate that sand bypassing from an interior sand trap has slowed the growth of the flood shoal, and has produced minimal impact on growth of the ebb shoal.

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